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SCIENCE

Dieldrin and DDT: Effects on Sparrow Hawk Eggshells and Reproduction

Abstract. *Patterns of reproductive failure in declining populations of several European and North American raptorial species were duplicated experimentally with captive American sparrow hawks* Falco sparverius *that were given a diet containing two commonly used organochlorine insecticides. Major effects on reproduction were increased egg disappearance, increased egg destruction by parent birds, and reduced eggshell thickness.*

Marked declines in populations and reproductive success of several species of North American and European raptors have occurred during the past two decades (*1–3*). These declines have been attributed to effects of organochlorine insecticides which these birds obtained from their food and accumulated in their tissues (*1, 3–5*). Reproductive failures of some species were associated with significant decreases in eggshell thickness (*6, 7*) and, especially in British species, with marked increase in frequency of egg-eating and of egg breakage in the nests (*5, 8*). These changes were ascribed to alterations in calcium metabolism of adult birds (*7*).

We have investigated effects of two sublethal dietary levels of DDT and dieldrin (*9*), in combination, on reproductive success of captive American sparrow hawks *Falco sparverius* and the influence of these chemicals on eggshell thickness.

The sparrow hawk was selected because it had been bred successfully in captivity on a limited scale (*10*), was relatively abundant, was easily handled and sexed, and was closely related to the peregrine falcon *F. peregrinus*, a declining species of raptor (*1*).

The principal experimental group consisted of 27 pairs of hawks, all obtained as fledglings in the summer of 1964 from the Northeast and maintained as pairs since early in 1965. Nine pairs of these birds were randomly assigned to each of three treatments —control, low dosage, and high dosage (*11*). An additional group of nine pairs of hawks that had a heterogeneous history and were housed at a different location were randomly assigned, three pairs each, to the same treatments as the principal group. Females of this latter group were birds caught from the wild in Florida in the winter of 1965–66; males were produced by the parent colony in 1965 before dosage began on 11 March 1966.

Low dosage represented amounts equal to residues often found in raptor food items in the field (*12*). High dosage was calculated to be just short of lethal to adults and it was equivalent to that obtainable in the field, at least in some areas containing prey items with unusually high pesticide residues (*13*).

Birds of both sexes were carried over from one year of the experiment to the next. Females that died during the experiment were not replaced. Males that died during the experiment were replaced at the onset of each reproductive season. Dosed males that died were replaced with males of the same treatment when available; otherwise, they were replaced with nondosed males.

In 1968, reproduction of first-generation (yearling) hawks was investigated. These hawks were produced by the experimental colony in 1967 and were retained on the same diet as their parents. The 24 pairs of hawks used in this experiment were selected on the basis of body condition. In pairing them, the heaviest females were mated with the heaviest males to insure successful pairing. Siblings were not paired with each other. Dosages were randomly assigned to pens. In respect to age and history of pesticide exposure, yearling hawks were our most homogeneous group.

To determine whether a mixture of DDT and dieldrin could cause thinning of eggshells, we marked the first egg

Table 1. Reproductive success of treated sparrow hawks. Data were analyzed by chi-square and presented as numbers of birds or eggs. Abbreviations: C, control; L, low dosage; H, high dosage (*11*).

Category	Parental group												Yearling group 1968		
	Northeastern females						Florida females								
	1967			1968			1967			1968					
	C	L	H	C	L	H	C	L	H	C	L	H	C	L	H
Pairs (clutches)	8	8	7	8	8	7	2	3	3	2	2	3	8	8	8
Eggs laid	40	40	33	39	40	32	10	14	13	10	10	13	41	33	42
Eggs taken for study	0	0	0	8	8	7	0	0	0	2	2	3	8	6	8
Eggs incubated	40	40	33	31	32	25	10	14	13	8	8	10	33	27	34
Eggs disappeared*	1	7†	9†	2	8†	10†	0	2	2	0	0	0	0	7†	4†
Eggs remaining	39	33	24	29	24	15	10	12	11	8	8	10	33	20	30
Infertile eggs‡	1	0	3	1	2	2	0	1	3	1	0	0	2	1	2
Dead embryos	6	9	2	13	6	3	0	2	0	2	5	6	3	0	9§
Eggs hatched of eggs incubated	32	24‖	19†	15	16	10	10	9†	8†	5	3	4	28	19	19†
Young fledged of eggs incubated	30	22¶	18¶	13	13	4§	7	8	7	4	3	4	28	19	13§
of eggs hatched	30	22	18	13	13	4§	7	8	7	4	3	4	28	19	13§

* May include disappearance of some young early in the post-hatching period. † Significant difference between dosed group and controls at $P < .05$. ‡ Refers to eggs without obvious embryonic development. § Significant difference between dosed group and controls and also from other dosed group at $P < .05$. ‖ Significant difference between dosed group and controls at $P \approx .06$. ¶ Significant difference between dosed group and controls at $P \approx .07$.

laid in each clutch, where possible, of both the parental and yearling groups in 1968, and removed it after the third egg was laid and before incubation was begun. All eggs collected were frozen, and their contents were removed later. The remaining albumen was then gently washed from the inner shell surface, so as not to disturb the shell membranes. Shells were then dried at room temperature for several weeks. Thickness of each shell plus its membranes was measured to the nearest 0.01 mm at four points around its equator with a micrometer, and these measurements were then averaged.

Reproductive success of untreated hawks in 1967 and 1968 was equal to that of a wild population, except for that of parental birds in 1968 (*14*). Reduced success of the parental group in 1968 was due mainly to embryonic mortality (Table 1) which may have been caused by bacterial infection of the eggs (*14*).

The influence of the pesticides on reproductive success was greatest in the yearling group (Table 1). Differences between yearling control and yearling dosed birds were significant ($P < .05$) at most major points of their reproductive cycle (Table 1). The same trend was apparent in the parental group in both 1967 and 1968 (Table 1), but differences between control and dosed groups were not always significant ($P < .05$).

The crucial factor responsible for reproductive failure of dosed birds was disappearance of eggs through time of hatching and may have included the disappearance of some newly hatched young. Differences in egg disappearance between dosed and control hawks were significant ($P < .05$) in most experimental groups (Table 1). Egg disappearance probably was due to breakage of thin-shelled eggs and to eating of eggs or newly hatched young by parent birds. Reproductive failures in declining populations of British raptors were similarly characterized by egg disappearance, egg breakage, and egg-eating by the parents (*8*).

Eggshells of dosed birds of the parental generation in 1968 were thinner by 8 to 10 percent on the average than those of controls of the parental group; eggshells of the first-generation dosed birds were thinner by 15 to 17 percent on the average than those of first-generation controls (Table 2). These differences were significant in both the first ($P < .01$) and parental ($P = .056$) generations of hawks. These reductions in shell thickness approached those that occurred after 1947 in declining populations of peregrine falcons both in the United States (18.8 to 26.0 percent) (*6*) and in Great Britain (19 percent) (*7*). Reductions in shell thickness also have occurred in declining populations of bald eagles *Haliaeetus leucocephalus* (18.0 to 19.8 percent) and ospreys *Pandion haliaetus* (25.1 percent) in the United States (*6*), and also in golden eagles *Aquila chrysaetos* (9 percent) and sparrow hawks *Accipiter nisus* (16 to 25 percent) in Great Britain (*7*).

The occurrence of the same pattern of reproductive failure among dosed birds for two consecutive years and in both parents and offspring strengthens the hypothesis that chlorinated-hydrocarbon pesticides have reduced the reproductive success of bird- and fish-eating raptors. The remarkable similarity in pattern of reproductive failure between our experimental hawks and wild raptor populations strongly supports the hypothesis that recent reproductive failures in several raptor populations in the United States and Western Europe were due to common physiological and behavioral responses to intake of sublethal amounts of persistent chlorinated hydrocarbons.

Table 2. Changes in thickness of sparrow hawk eggshells. Data were analyzed by analysis of variance; Duncan's new multiple range test was used to test differences between means. Abbreviations: C, control; L, low dosage; H, high dosage (*11*).

Experimental group	Treatments							
	C		L			H		
	No.	Average shell thickness (mm)	No.	Average shell thickness (mm)	Deviation from control (%)	No.	Average shell thickness (mm)	Deviation from control (%)
Parental group*								
1967	8	0.197	5	0.177	10	10	0.165	16
1968	10	0.189	10	0.173†	8	10	0.170‡	10
First-generation group (yearlings) 1968	8	0.198	8	0.164§	17	8	0.168§	15

* Eggs of the parental group in 1967 were haphazard samples. Although they suggested the occurrence of thickness differences, they were not suitable for a reliable statistical test. The parental group contained birds from both the Northeastern United States and Florida. A randomized block design permitted the inclusion of data from both these sources for 1968. † Significant difference between dosage group and controls at $P \approx .06$. ‡ Significant difference between dosage group and controls at $P < .05$. § Significant difference between dosage group and controls at $P < .01$.

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9. DDT is 1,1,1-trichloro-2,2-bis(*p*-chlorophenyl)-ethane; dieldrin is composed of 95 percent HEOD, which is 1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-endo, exo-5,8-dimethanonaphthalene.
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11. The high-treatment group was given a diet containing 3 ppm of dieldrin plus 15 ppm of *p,p'*-DDT, dry weight basis (0.84 ppm dieldrin and 4.7 ppm DDT, wet weight); food of the low-treatment group contained 1 ppm of dieldrin plus 5 ppm of *p,p'*-DDT, dry weight basis (0.28 ppm dieldrin and 1.4 ppm DDT, wet weight); no insecticide was added to the food of the control group. Toxicants were dissolved in cottonseed oil and mixed into a diet of ground meat. Clean oil was added to the food of the control birds in amounts equal to that added to the diets of each of the dosed groups.
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DDT Residues in Starlings, 1974

Paul R. Nickerson [1] and Kyle R. Barbehenn [2]

ABSTRACT

In the preceding issue of this journal, the authors suggested that the mean level of DDT plus metabolites in starlings should drop below 0.1 ppm for the 1974 collection. They based their prediction on an analysis of the relationship between mean levels of DDT and its metabolites in starlings and estimates of domestic disappearance of DDT. The present brief summarizes initial findings from the 1974 starling collection. Authors indicate that their earlier estimates for disappearance of total DDT were optimistic: the geometric mean for 1974 was 0.282, a 36 percent reduction from the 1972 mean of 0.442.

Introduction

Based upon an analysis of the relationship between mean levels of DDT and its metabolites in starlings and estimates of domestic disappearance of DDT, authors suggested in the preceding issue of this periodical that the residue levels of these organochlorines in starlings should drop below a mean of 0.1 ppm for the 1974 collection (*1*).

Analytical Results

Residue analysis results from the 1974 collection are now in hand and it is apparent that the extrapolation from a small data base was overly optimistic. The geometric mean of DDT plus metabolites is 0.282 ppm for 1974.

Of the 122 sites sampled, 17 of the values exceeded 1.0 ppm and 2 (3G3 in Arkansas and 4C1 in Arizona; see Tables 1,3) reached a level of 9.2 ppm. Although the reduction of 0.160 ppm (36 percent) from the mean level of 1972 (0.442 ppm) is substantial it is clear that DDT remains by far the most abundant source of pesticide residues found in starlings two full growing seasons after the major uses of DDT were cancelled.

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(*1*) *Nickerson, Paul R., and Kyle R. Barbehenn. 1975.* Organochlorine residues in starlings, 1972. Pestic. Monit. J. 8(4):247-254.

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Organochlorine Residues in Starlings, 1972

Paul R. Nickerson [1] and Kyle R. Barbehenn [2]

ABSTRACT

During the fall of 1972 starlings were collected from 130 sites in conjunction with the National Pesticide Monitoring Program. They were analyzed for DDT and its metabolites, dieldrin, heptachlor epoxide, benzene hexachloride, polychlorinated biphenyls and, for the first time in the series, oxychlordane and HCB. Mean DDT and dieldrin residue levels have declined significantly since 1967 and a regression analysis suggests that levels of DDT and its metabolites should fall below a mean of 0.1 ppm for the 1974 starling collection.

Introduction

As part of the National Pesticide Monitoring Program, a nationwide sample of starlings is collected and analyzed biennially to help measure environmental levels of persistent organochlorine compounds. Data for residues of these contaminants were first derived from analyses of three collections taken in 1967 and 1968 and reported by Martin in 1969 (*1*). The rationale for selecting starlings as a subject species appeared in that pilot study: they are a terrestrial avian species found year-round throughout most of the contiguous United States; they are generally regarded as expendable; and their omnivorous feeding habits can be expected to reflect pesticide intake from insects, fruits, grain, and miscellaneous other foods. Collections from fall 1970 were reported by Martin and Nickerson in 1972 (*2*). The present paper presents data from the fall 1972 collection and compares portions of the data to those obtained in previous collections. Using these data, authors can examine some trends with greater confidence than in past studies and make tentative estimates for residue levels of DDT and dieldrin in future collections. Focus of the estimates will be national rather than regional, leaving the problem of substantial geographical variation for the future.

Sampling

As described in previous publications, the sampled area is composed of 40 blocks of 5° latitude and longitude, ranging from 24° to 49° latitude and 64° to 124° longitude (*1,2*). One to four starling sampling sites were randomly selected from each block. The same sites have been used for all collections. Figure 1 shows the location of all sampling sites and Table 1 lists locations successfully sampled during the November-December 1972 collection. Each sample location is identified by a row number, a column letter, and a site number: e.g., the site near Tacoma, Wash., is designated 1-A-1. In 1972, collections were made at 130 (94 percent) of 139 sampling locations.

In previous years, Texas, a State of high pesticide use, posed a major problem. Thus collection efforts were intensified in 1972 and collections were successful in five of the nine preselected sites. Hopefully sampling in Texas will be improved further by extending the collection period into January when the starlings are in larger flocks.

Most starling samples consisted of a pool of 10 birds which had been trapped or shot. Each pool was wrapped in aluminum foil, placed in polyethylene bags, and frozen for shipment to the laboratory.

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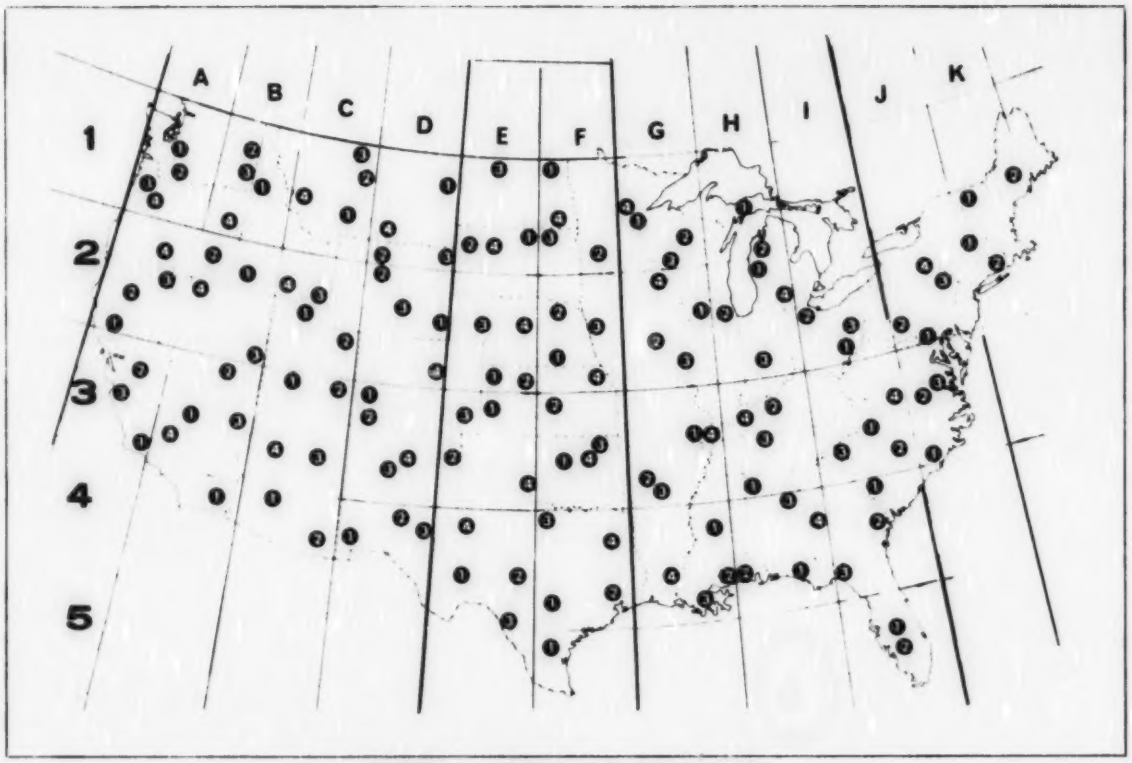

FIGURE 1. *Starling monitoring sites, 1972*

Analytical Methods

Residue analyses were performed as described previously (*1,2*) by WARF Institute, Inc., under contract with the U.S. Department of Interior—Bureau of Sport Fisheries and Wildlife (predecessor of the Fish and Wildlife Service). Technicians prepared the birds by removing their beaks and feet, then skinning their bodies. Each pool was ground in a Hobart food chopper until homogenized. The only major change in methodology involved use of 11 percent OV-17 + QF-1 (mixed phase) on 80/100 Gas-Chrom Q in the second column. Flow rate involved a retention time of 4-5 minutes for heptachlor epoxide. This new procedure separated oxychlordane from heptachlor epoxide, and HCB from BHC.

For the determination of DDE, DDD, DDT, dieldrin, and polychlorinated biphenyls (PCB's), instrument conditions were:

Temperatures:	Column 200° C. Injector 230° C. Detector 240° C.
Column:	4-ft-by-4-mm glass packed with 5 percent DC-200 on 80/100 Gas-Chrom Q.
Carrier Gas:	Nitrogen.
Flow:	Involved retention time of 6-8 minutes for *p,p'*-DDT.

For the determination of HCB, alpha BHC, gamma BHC (lindane), beta BHC, heptachlor epoxide, and oxychlordane, instrument conditions were:

Temperatures:	Column 180° C. Injector 220° C. Detector 235° C.
Column:	4-ft-by-4-mm 11 percent OV-17 + QF-1 (mixed phase) on 80/100 Gas-Chrom Q (available from Applied Science Cat. No. 12970).
Carrier Gas:	Nitrogen.
Flow:	Involved retention time of 4-5 minutes for heptachlor epoxide.

Recovery rates for DDE, DDD, DDT, PCB's, dieldrin, and BHC ranged from 78 to 97 percent. Residue data were not corrected for recovery. Recovery and confirmatory tests were performed internally by the commercial laboratory on a quality control basis. Limits of detection ranged from 0.005 to 0.1 ppm.

TABLE 1. *Starling sampling sites listed by State and county, 1972*

State	County	Site Number
Alabama	Marion	3-H-1
	Talladega	4-H-3
Arizona	Navajo	3-C-3
	Yavapai	3-C-4
	Maricopa	4-C-1
	Graham	4-C-2
Arkansas	Yell/Pope	3-G-2
	Lonoke/Pulaski	3-G-3
California	Colusa	2-A-1
	Shasta	2-A-2
	Modoc	2-A-3
	Ventura	3-A-1
	Stanislaus	3-A-2
	Monterey	3-A-3
	Inyo	3-B-1
	Kern	3-B-4
	Imperial	4-B-1
Colorado	Weld	2-D-4
	Montrose	3-D-1
	Crowley	3-D-2
Connecticut	New London	2-D-2
Florida	Bay	4-H-1
	Madison	4-I-3
	Polk	5-I-1
	Hardee	5-I-2
Georgia	Pike	4-H-4
	Wayne	4-I-2
Idaho	Nez Perce	1-B-1
	Owyhee	2-B-1
	Franklin	2-C-3
	Minidoka	2-C-4
Illinois	Stephenson	2-G-1
	Adams	2-G-3
	Kane	2-H-2
Indiana	Hendricks	2-H-3
Iowa	Fremont	2-F-3
	Jasper	2-G-2
	Marshall	2-G-4
Kansas	Rawlins	2-E-1
	Phillips	2-E-2
	Kearny	3-E-1
	Nemaha	2-F-4
	Marion	3-F-2
Kentucky	Ohio	3-H-2
	Hopkins	3-H-4
Louisiana	Jefferson	4-G-3
	Rapides	4-G-4
Maine	Penobscot	1-K-2
Maryland	Prince Georges	2-J-1
Michigan	Chippewa	1-H-1
	Grand Traverse	1-H-2
	Kent	2-H-1
	Ingham	2-H-4
Minnesota	Aitkin	1-G-4
Mississippi	Leake	4-G-1
	Harrison	4-G-2
	Jackson	4-H-2
Missouri	Butler	3-G-1
	Bollinger	3-G-4
Montana	Meagher	1-C-1
	Blaine	1-C-2
	Missoula	1-C-4
	Richland	1-D-1
	Yellowstone	1-D-4
Nebraska	Keith	2-E-3
	Brown	2-E-4
	Lancaster	2-F-1
	Clay	2-F-2
Nevada	White Pine	2-B-3
	Humboldt	2-B-4
	Nye	3-B-2
	Clark	3-B-3
New Mexico	Bernalillo	3-D-3
	Torrance	3-D-4
	Luna	4-D-1
	Otero	4-D-2
	Chaves	4-D-3
	Quay	3-E-2
New York	Jefferson	2-J-4
	Rensselaer	2-K-1
North Carolina	Wilkes	3-I-1
	Union	3-I-2
	Macon	3-I-3
	Pender	3-J-1
North Dakota	McLean	1-E-3
	Grand Forks	1-F-1
	Ransom	1-F-4
Ohio	Pickaway	2-I-1
	Wood	2-I-2
	Noble	2-I-3
Oklahoma	Greer	3-E-4
	Canadian	3-F-1
	Nowata	3-F-3
	Okmulgee	3-F-4
Oregon	Yamhill	1-A 3
	Lane	1-A-4
	Klamath	2-A-4
	Baker	1-B-4
	Harney	2-B-2
Pennsylvania	Somerset	2-J-2
	Luzerne	2-J-3
South Carolina	Aiken	4-I-1
South Dakota	Potter	1-E-1
	Butte	1-E-2
	Hughes	1-E-4
	Brown	1-F-3
Tennessee	Davidson	3-H-3
Texas	Kinney	4-E-3
	Cochran	4-E-4
	Comal	4-F-1
	Clay	4-F-3
	San Patricio	5-F-1
Utah	Weber	2-C-1
	Duchesne	2-C-2
	Sevier/Millard	3-C-1
	Grand	3-C-2
Vermont	Addison	1-K-1
Virginia	Amherst	3-I-4
	Prince George	3-J-2
	Caroline	3-J-3
Washington	Pierce	1-A-1
	Yakima	1-A-2
	Spokane	1-B-2
	Whitman	1-B-3
Wisconsin	Clark	1-G-2
	Trempealeau	1-G-3
Wyoming	Big Horn	1-D-2
	Crook	1-D-3
	Goshen	2-D-1
	Washakie	2-D-2

Statistical Procedures

National averages for DDT with its metabolites and dieldrin from all five collections were calculated by two methods (Table 2). The geometric mean provides an appropriate measure of central tendency and should approximate the median value in these skewed distributions (see reference *2*, Table 4). The arithmetic means average 2.2 times higher than the geometric means for DDT and metabolites, and 2.7 times higher for dieldrin. The arithmetic mean is a better measure of environmental load and is the appropriate value to use in determining, for example, how much pesticide a Cooper's hawk would be likely to ingest if it ate 100 starlings. The estimate cannot be precise because of the low probability of encountering starlings with unusually high concentrations of pesticides (Tables 3,4). In calculating the means, values given as <0.015-<0.010 ppm in the pilot study of this series (*1*) were assigned values of 0.005 ppm. For 1972, trace was called 0.002 ppm.

The confidence intervals around the geometric means reflect the nationwide variability in residue levels and are not the most sensitive indicators of differences between the annual means. Residue values of DDT and its metabolites from each station were compared with those of dieldrin for the periods summer-winter 1967-68 versus fall 1968, fall 1968 versus fall 1970, and fall 1970 versus fall 1972. Statistically significant correlation coefficients ranged from 0.59 to 0.70 for DDT and from 0.26 to 0.56 for dieldrin, indicating that a sign test (*3*) for paired values is an appropriate measure of temporal differences, even though the residual variance is high.

Having established that certain differences between years were statistically significant, regression analysis

TABLE 2. *Geometric and arithmetic means of DDT and dieldrin residues in starlings, 1972*

Collecting Period	No. Stations Sampled	Lipids, % Wet Weight	DDT & Metabolites, ppb Wet Weight	Dieldrin, ppb Wet Weight
Summer 1967	116	3.20 (3.01-3.41)	679 (536-861) AM 1755	27 (21-34) AM 82
Winter 1967-68	122	7.42 (6.99-7.87)	830 (670-1028) AM 2019	99 (74-134) AM 240
Fall 1968	122	5.84 (5.47-6.23)	569 (473-685) AM 1135	40 (32-49) AM 84
Fall 1970	125	5.40 (5.00-5.82)	445 (366-539) AM 916	36 (29-46) AM 117
Fall 1972	130	6.24 (5.89-6.61)	442 (420-464) AM 847	35 (28-45) AM 98

NOTE: Values in parentheses represent 95 percent confidence intervals for geometric mean.
AM = Arithmetic mean.

TABLE 3. *Sites with residue levels of DDT and its metabolites greater than 3.0 ppm in baseline, 1970, or 1972 collections*

Site Number	DDT Residues, ppm		
	Baseline Data, 1967-68	1970	1972
3-A-1	1.903	3.660	1.930
3-B-4	4.376	2.837	2.330
2-C-2	9.551	NS	0.640
3-C-2	3.163	NS	0.610
4-C-1	23.902	14.874	0.140
4-D-1	1.930	4.780	1.100
4-D-3	19.680	1.479	3.550
2-E-1	0.199	0.202	4.130
3-E-4	4.948	5.318	0.330
3-G-3	5.950	5.313	8.040
4-G-1	8.128	3.413	4.950
4-G-2	1.580	4.801	0.710
4-G-4	4.220	1.210	11.800
4-H-3	2.347	3.060	3.290
4-H-4	3.510	2.546	0.880
4-I-1	5.483	3.026	5.080
4-I-3	5.668	3.872	1.680

NOTE: NS = No sample collected.

TABLE 4. *Sites with residue levels of dieldrin greater than 0.3 ppm in baseline, 1970, and/or 1972 collections*

Site Number	Dieldrin Residues, ppm		
	Baseline Data, 1967-68	1970	1972
1-A-3	0.528	0.160	0.160
1-A-4	0.492	0.140	0.130
1-B-1	0.115	0.050	1.560
1-B-2	0.237	0.280	0.710
1-B-3	0.587	0.600	0.037
1-B-4	0.418	0.018	0.009
3-E-1	0.102	0.420	0.041
2-G-1	0.280	0.590	0.090
2-G-3	0.657	3.590	0.390
2-G-4	0.032	1.520	0.310
3-G-1	0.403	0.230	0.260
3-G-3	0.317	0.067	0.110
3-G-4	0.207	0.520	0.350
4-G-2	0.970	0.067	0.011
2-H-2	0.208	0.330	0.170
2-H-3	0.056	0.260	0.340
4-H-1	0.135	0.087	0.310
2-I-2	0.193	0.230	0.730
3-I-1	1.385	0.018	0.076
4-I-2	0.027	0.750	0.022
4-I-3	0.055	0.044	1.200
3-J-1	0.333	0.160	0.530

was used to determine the relationship between residue levels and estimates of pesticide usage. The residue values for fall 1967 were estimated by converting the summer and winter values to a lipid basis and interpolating on a logarithmic scale. Mean lipid values from the three fall collections (Table 2) were then used to estimate the wet-weight residue concentrations for the missing collection.

Residue levels of organochlorine compounds from the 130 stations sampled in 1972 are presented in Table 5.

Results and Discussion

DDT AND METABOLITES

Differences between the residue levels in collections from summer 1967 and winter 1967-68 were not statistically significant (Table 2). Levels in the fall 1968 samples, however, were consistently lower than those found in the corresponding averages for the summer/winter samples, suggesting that a significant change in residue levels had occurred within what had been considered the baseline periods (*1*). Pesticide use preceding the four fall periods was assumed to be proportional to U.S. Department of Agriculture values for domestic disappearance (*4*). Residue levels and pesticide use are highly correlated (Fig. 2) and an extrapolation from the data points predicts a mean residue level well below 0.1 ppm for 1974.

Considerable caution should be exercised in projecting estimates far beyond this data base. The high correlation from only four data points could be fortuitous; authors believe use patterns to be more relevant than mere tonnage in determining exposure. Results from 1974 should provide a more reliable fix on the slope.

Sites having DDT and metabolite residues greater than 3.0 ppm in baseline, 1970, and/or 1972 are listed in Table 3. Sites containing the highest DDT and metabolic levels in 1972 (greater than 3.0 ppm) were found in southeastern New Mexico (4-D-3), northwestern Kansas (2-E-1), central Arkansas (3-G-3), central Louisiana (4-D-3), north-central Alabama (4-H-3), and South Carolina (4-I-1).

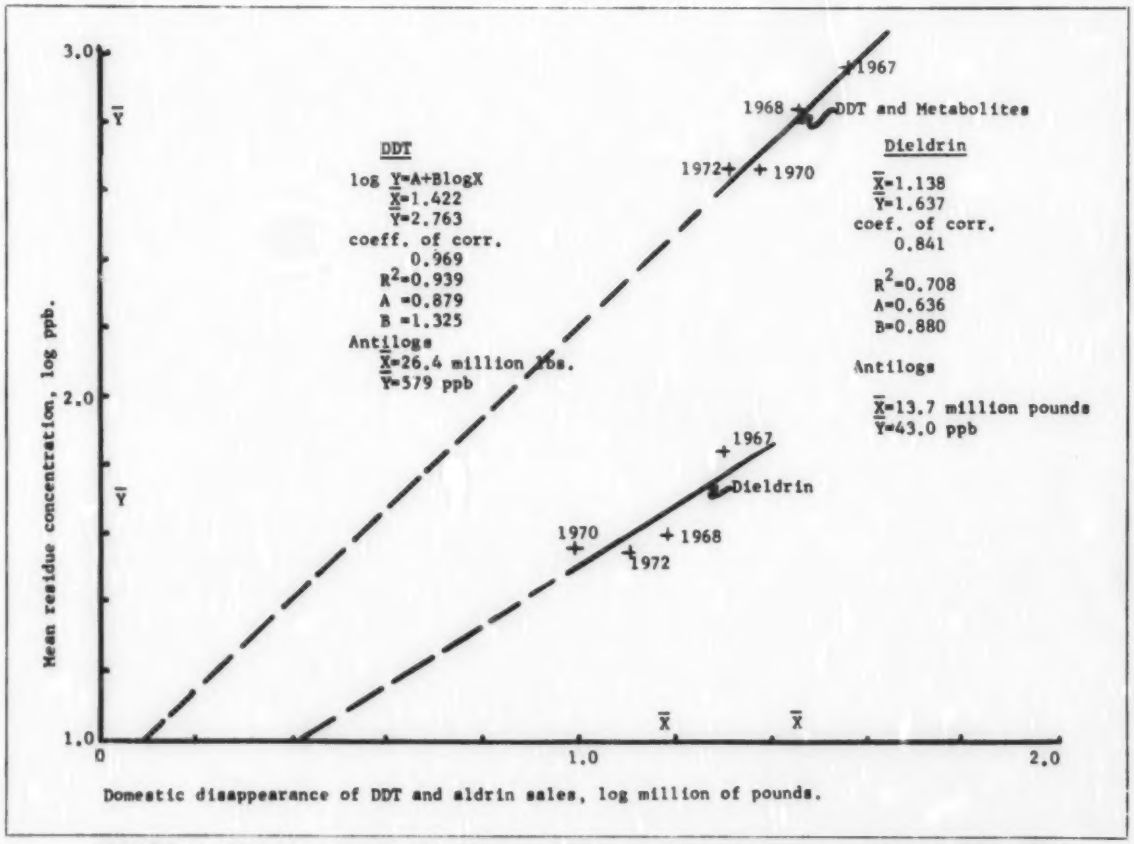

FIGURE 2. *Regressions of pesticide residues in starlings on indices of pesticide use, 1967-68, 1970, 1972*

TABLE 5. *Organochlorine residue levels in starlings, 1972*

Site No.[1]	Wet Weight, g	Lipid Weight, g	DDE	DDD	DDT	DDT/ Metabolites	PCB's [2]	Dieldrin	Heptachlor Epoxide	Oxychlordane	BHC	HCB
1-A-1	20.03	1.28	0.310	0.017	0.031	0.360	0.360	0.086	0.008	0.007	0.006	0.007
1-A-2	19.97	1.50	1.390	0.006	0.011	1.410	0.063	0.140	0.026	TR	0.036	3.330
1-A-3	20.24	0.83	0.950	0.015	0.017	0.980	0.140	0.160	TR	TR	ND	0.036
1-A-4	20.00	1.19	0.780	0.017	0.019	0.820	0.160	0.130	0.006	TR	TR	0.011
2-A-1	20.16	0.53	0.470	0.008	0.010	0.490	0.074	0.021	TR	TR	0.011	0.011
2-A-2	20.08	0.85	0.630	TR	0.010	0.640	0.100	0.035	0.009	TR	TR	0.014
2-A-3	20.02	1.69	0.077	TR	0.005	0.082	0.056	0.016	TR	TR	0.007	0.011
2-A-4	20.09	1.13	0.490	0.520	0.017	1.030	0.110	0.050	0.013	TR	0.007	0.066
3-A-1	20.10	0.85	1.900	0.014	0.019	1.930	0.170	0.016	0.005	0.008	TR	0.012
3-A-2	20.10	1.06	0.940	0.022	0.053	1.010	0.420	0.037	TR	0.005	TR	TR
3-A-3	20.00	1.32	0.300	0.011	0.019	0.330	0.190	0.019	0.006	0.006	0.007	TR
1-B-1	20.02	1.89	0.660	0.028	0.021	0.710	0.120	1.560	0.009	TR	0.006	2.340
1-B-2	20.03	2.91	0.300	0.014	0.021	0.330	0.170	0.710	0.010	0.007	TR	0.590
1-B-3	20.06	0.95	0.190	TR	0.011	0.200	0.037	0.037	0.210	0.010	0.035	0.550
1-B-4	20.33	1.36	0.150	0.008	0.012	0.170	0.100	0.009	TR	TR	0.010	0.036
2-B-1	20.09	0.98	0.270	0.011	0.029	0.310	0.230	0.060	0.007	TR	0.006	0.057
2-B-2	20.15	1.27	0.170	0.008	0.017	0.200	0.120	0.019	TR	TR	0.009	0.006
2-B-3	20.04	1.96	0.650	0.006	0.014	0.670	0.250	0.046	0.025	ND	0.009	0.007
2-B-4	20.20	1.58	0.240	TR	0.006	0.250	0.099	0.019	0.011	0.006	0.006	0.009
3-B-1	20.02	0.62	2.340	0.009	0.034	2.380	0.370	0.070	0.017	0.017	0.005	0.018
3-B-2	20.29	0.91	0.180	TR	0.006	0.190	0.099	0.039	TR	0.009	0.006	0.005
3-B-3	20.05	1.56	0.620	0.047	0.160	0.830	1.870	0.270	0.053	0.031	0.009	0.037
3-B-4	20.01	1.39	2.310	TR	0.022	2.330	0.140	0.037	TR	0.006	TR	0.024
4-B-1	20.01	0.75	1.440	TR	0.017	1.460	0.190	0.026	TR	TR	TR	0.009
1-C-1	20.54	1.26	0.091	0.009	0.032	0.1..	0.370	0.025	0.046	0.030	0.010	0.006
1-C-2	20.05	1.28	0.078	0.016	0.019	0.110	0.210	0.021	0.050	0.009	0.016	0.007
1-C-4	20.48	1.05	0.081	0.013	0.024	0.120	0.290	TR	0.009	ND	0.005	0.009
2-C-1	20.18	1.39	0.350	TR	0.015	0.370	0.150	0.017	0.008	0.006	0.006	TR
2-C-2[3]	20.24	1.13	0.630	TR	0.007	0.640	0.068	TR	0.008	TR	TR	TR
2-C-3	20.11	1.02	0.530	0.006	0.012	0.550	0.120	0.017	0.027	0.009	0.005	TR
2-C-4	20.14	1.66	0.970	0.006	0.012	0.990	0.087	0.028	0.021	0.007	0.006	0.006
3-C-1	20.00	1.66	0.630	TR	0.009	0.640	0.150	0.034	0.011	0.008	0.006	TR
3-C-2[4]	20.16	1.60	0.590	0.006	0.011	0.610	0.200	0.160	0.012	0.007	0.006	0.006
3-C-3	20.02	0.99	0.590	0.005	0.020	0.610	0.250	0.012	TR	TR	TR	TR
3-C-4	19.98	1.01	0.490	TR	0.014	0.500	0.110	0.300	0.007	0.006	0.006	TR
4-C-1	19.99	1.82	0.130	TR	0.009	0.140	0.081	0.021	0.008	TR	0.011	0.025
4-C-2	19.99	0.91	1.490	0.011	0.022	1.520	0.160	0.020	0.006	TR	0.006	TR
1-D-1	20.34	1.39	0.025	TR	TR	0.025	0.037	0.018	0.005	TR	0.006	TR
1-D-2[5]	20.09	1.02	0.077	TR	0.006	0.083	0.100	0.005	0.006	TR	TR	TR
1-D-3[6]	20.02	1.66	0.058	0.011	0.052	0.120	0.730	0.009	0.007	TR	0.006	0.005
1-D-4	20.38	1.85	0.076	TR	0.009	0.085	0.061	0.025	0.007	TR	0.005	0.007
2-D-1	19.95	1.49	0.071	0.008	0.017	0.096	0.250	0.006	0.010	ND	TR	0.005
2-D-2[4]	20.16	0.72	0.050	TR	0.006	0.056	0.099	0.006	0.009	ND	0.007	TR
2-D-4	20.06	1.75	0.220	TR	0.016	0.240	0.190	0.049	0.011	0.011	0.007	TR
3-D-1	20.05	0.92	0.260	TR	0.012	0.270	0.120	0.066	0.013	0.013	TR	TR
3-D-2	20.02	1.34	0.079	TR	0.009	0.088	0.094	0.007	TR	TR	0.009	TR
3-D-3	20.04	0.91	0.470	0.017	0.042	0.530	0.450	0.007	TR	TR	TR	TR
3-D-4	20.06	1.25	0.790	0.005	0.014	0.800	0.160	0.021	TR	TR	0.010	TR
4-D-1	19.99	0.85	1.090	TR	0.013	1.100	0.160	0.010	TR	TR	TR	0.005
4-D-2	19.90	0.61	0.630	TR	0.009	0.640	0.130	0.005	TR	TR	TR	TR
4-D-3	19.99	1.26	3.520	0.013	0.019	3.550	0.190	0.028	0.019	0.008	TR	0.007
1-E-1	20.01	2.00	0.120	0.009	0.022	0.150	0.120	TR	0.005	ND	TR	TR
1-E-2	20.11	1.60	0.068	0.008	0.017	0.093	0.190	0.007	0.005	ND	0.006	TR
1-E-3	20.12	0.95	0.078	0.005	0.007	0.085	0.099	0.009	0.005	TR	TR	TR
1-E-4	20.13	2.10	0.023	0.008	0.027	0.058	0.220	0.007	0.006	ND	0.009	TR
2-E-1	19.98	0.87	4.070	0.023	0.040	4.130	0.360	0.041	0.019	0.005	0.008	TR
2-E-2	20.01	1.42	0.190	0.014	0.036	0.240	0.270	0.005	0.017	0.005	0.016	0.007
2-E-3	20.16	1.26	0.110	TR	0.006	0.120	0.081	0.005	TR	0.011	0.006	TR
2-E-4	20.13	1.16	0.056	0.005	0.012	0.073	0.160	0.024	TR	TR	0.007	TR
3-E-1	20.03	1.62	0.120	TR	0.005	0.120	0.062	0.041	0.009	TR	0.007	0.009
3-E-2	20.02	0.95	0.150	0.014	0.059	0.220	0.520	0.017	0.019	TR	0.006	0.027
3-E-4	20.03	0.93	0.320	TR	0.007	0.330	0.094	0.100	0.038	0.009	0.007	0.006
4-E-3	20.14	1.23	2.060	0.006	0.013	2.080	0.200	0.048	0.011	0.007	TR	0.007
4-E-4	20.23	1.03	1.020	TR	0.006	1.030	0.074	0.043	0.019	0.009	TR	0.009
1-F-1	20.09	0.51	0.270	TR	0.007	0.280	0.100	0.005	0.006	TR	TR	TR
1-F-3	20.08	1.60	0.032	0.005	0.012	0.049	0.160	0.008	0.006	TR	TR	TR
1-F-4	20.28	2.14	0.044	TR	0.005	0.049	0.068	TR	TR	TR	0.007	TR
2-F-1	20.21	1.86	0.330	0.027	0.046	0.400	0.520	0.060	0.027	0.013	0.009	TR
2-F-2	20.21	1.77	0.230	TR	0.007	0.240	0.099	0.074	0.020	0.012	0.012	0.005
2-F-3	20.09	1.33	0.170	TR	0.012	0.180	0.110	0.260	0.034	0.007	TR	TR
2-F-4	20.04	1.41	0.130	TR	0.012	0.160	0.094	0.024	0.009	TR	0.011	0.006

TABLE 5 (cont'd). *Organochlorine residue levels in starlings, 1972*

Site No.[1]	Wet Weight, g	Lipid Weight, g	DDE	DDD	DDT	DDT/ Metabolites	PCB's [2]	Dieldrin	Heptachlor Epoxide	Oxychlordane	BHC	HCB
3-F-1	20.52	1.21	0.130	TR	0.014	0.140	0.150	0.072	0.017	0.007	TR	0.023
3-F-2	19.97	1.19	0.420	TR	0.012	0.430	0.130	0.012	TR	TR	TR	TR
3-F-3	20.03	1.54	0.370	0.032	0.080	0.480	0.840	0.017	0.008	0.006	0.012	TR
3-F-4	20.12	2.14	0.440	TR	0.019	0.460	0.190	0.033	0.007	TR	TR	TR
4-F-1[3]	20.10	1.09	1.060	TR	0.011	1.070	0.200	0.027	0.012	0.012	TR	0.025
4-F-1	20.13	1.10	0.620	TR	0.016	0.640	0.200	0.016	0.017	0.011	TR	TR
5-F-1	20.18	1.75	1.040	0.029	0.036	1.110	0.280	0.061	0.011	0.005	TR	0.008
1-G-2	20.15	1.26	0.230	0.008	0.022	0.260	0.220	0.027	0.009	TR	0.006	0.022
1-G-3	20.11	2.11	0.390	0.023	0.053	0.470	0.550	0.016	0.017	0.014	0.009	0.006
1-G-4	20.28	1.67	0.150	0.017	0.035	0.200	0.320	0.020	0.020	0.007	0.020	0.007
2-G-1	20.10	2.15	0.680	0.022	0.042	0.740	0.420	0.090	0.082	0.032	0.007	TR
2-G-2	20.01	2.21	0.110	0.006	0.013	0.130	0.100	0.280	0.077	0.016	0.006	TR
2-G-3	20.25	1.63	0.140	0.009	0.033	0.180	0.340	0.390	0.110	0.033	0.007	0.019
2-G-4	20.08	2.57	0.230	0.022	0.063	0.320	0.410	0.310	0.039	0.034	0.008	TR
3-G-1	20.04	1.49	0.550	0.025	0.029	0.600	0.210	0.260	0.034	0.014	0.006	0.011
3-G-2	20.05	1.04	0.220	0.012	0.077	0.310	0.720	0.035	0.057	0.028	0.008	0.014
3-G-3	20.04	1.14	7.950	0.044	0.049	8.040	0.220	0.110	ND	ND	TR	0.044
3-G-4	19.97	1.37	0.940	0.019	0.039	1.000	0.290	0.350	0.031	0.018	0.014	0.080
4-G-1	20.02	0.81	4.920	0.013	0.020	4.950	0.160	0.039	0.021	0.009	TR	0.024
4-G-2	20.09	0.92	0.680	TR	0.028	0.710	0.290	0.011	0.012	0.009	TR	0.009
4-G-3	20.11	0.84	0.710	TR	0.091	0.800	1.020	0.016	ND	ND	TR	0.044
4-G-4	20.29	1.71	11.700	0.089	0.046	11.800	0.220	0.150	0.065	0.018	0.011	TR
1-H-1	20.04	1.85	0.180	0.021	0.069	0.270	0.700	0.023	0.011	TR	0.007	0.007
1-H-2	19.96	1.26	0.680	0.054	0.059	0.790	0.370	0.023	0.008	0.008	0.005	TR
2-H-1	20.02	1.69	0.780	0.032	0.096	0.910	0.990	0.025	0.054	0.054	0.006	0.006
2-H-2	20.03	1.40	0.440	0.018	0.046	0.500	0.410	0.170	0.049	0.011	0.009	TR
2-H-3	20.04	1.15	0.560	0.011	0.026	0.600	0.250	0.340	0.031	0.007	TR	0.550
2-H-4	20.04	2.31	0.500	0.018	0.057	0.580	0.530	0.024	0.026	0.024	0.024	0.029
3-H-1	20.97	1.14	1.790	0.016	0.030	1.840	0.170	0.065	0.037	0.029	0.007	TR
3-H-2	20.00	1.79	0.130	0.020	0.049	0.200	0.520	ND	0.016	0.009	ND	0.140
3-H-3	20.06	1.16	0.440	0.006	0.031	0.480	0.370	0.030	0.011	0.012	TR	TR
3-H-4	20.07	1.28	0.660	TR	0.011	0.670	0.110	0.084	0.026	0.009	0.008	0.095
4-H-1	20.07	0.91	1.060	TR	0.022	1.080	0.290	0.310	0.091	0.100	TR	0.044
4-H-2	19.98	1.03	0.780	0.013	0.028	0.820	0.300	0.025	0.053	0.025	ND	0.059
4-H-3	22.04	1.06	0.890	0.840	1.560	3.290	19.900	0.029	0.071	ND	TR	TR
4-H-4	20.11	0.86	0.870	TR	0.013	0.880	0.250	0.280	0.028	TR	TR	TR
2-I-1	19.98	1.75	0.180	0.041	0.036	0.260	0.320	0.170	0.041	0.021	ND	0.210
2-I-2	20.05	1.79	0.500	0.046	0.065	0.610	0.650	0.730	0.150	0.034	0.012	0.280
2-I-3	20.02	1.44	0.260	0.009	0.031	0.300	0.250	0.028	0.024	0.010	0.018	0.046
3-I-1	20.02	0.77	0.370	0.016	0.042	0.430	0.470	0.076	0.023	0.025	TR	TR
3-I-2	20.03	0.94	1.090	0.009	0.040	1.140	0.440	0.160	0.011	0.009	TR	TR
3-I-3	20.01	0.90	0.150	0.006	0.016	0.170	0.160	0.028	0.008	0.006	TR	TR
3-I-4	20.90	0.77	0.570	TR	0.011	0.580	0.160	0.031	0.020	0.008	TR	0.007
4-I-1	20.03	0.88	5.040	0.015	0.024	5.080	0.190	0.050	0.041	0.012	TR	TR
4-I-2	20.00	1.07	0.600	0.011	0.053	0.660	0.860	0.022	ND	ND	TR	0.010
4-I-3	20.15	0.97	1.640	TR	0.037	1.680	0.410	1.200	0.014	0.038	TR	TR
5-I-1	20.02	0.78	0.460	TR	0.020	0.480	0.190	0.033	ND	ND	TR	TR
5-I-2	20.17	0.83	0.420	0.013	0.029	0.460	0.320	0.017	TR	0.011	ND	ND
2-J-1	20.08	0.45	0.380	0.008	0.021	0.410	0.230	0.120	0.022	0.015	TR	0.042
2-J-2	20.12	1.36	0.310	0.007	0.019	0.340	0.170	0.047	0.030	0.021	0.030	0.035
2-J-3	20.09	1.43	0.380	0.007	0.023	0.410	0.210	0.068	0.028	0.012	0.007	TR
2-J-4	20.09	2.02	0.150	0.007	0.016	0.170	0.200	0.011	TR	TR	TR	TR
3-J-1	21.21	1.12	1.110	0.014	0.039	1.160	0.390	0.530	0.038	0.035	ND	ND
3-J-2	20.05	1.05	1.610	0.008	0.056	1.670	0.520	0.130	ND	ND	TR	TR
3-J-3	20.01	1.25	0.530	0.031	0.046	0.610	0.540	0.097	0.021	0.027	ND	0.014
1-K-1	20.07	0.96	0.370	0.006	0.018	0.390	0.200	0.016	0.005	0.005	TR	TR
1-K-2	20.03	1.58	0.390	0.011	0.026	0.430	0.250	0.027	0.014	0.012	TR	TR
2-K-1	20.28	1.11	0.890	0.007	0.052	0.950	0.960	0.006	0.007	TR	0.005	0.008
2-K-2	20.22	1.17	0.250	0.012	0.026	0.290	0.290	0.021	0.019	0.019	TR	0.007

NOTE: Weights expressed in grams; residues expressed in ppm (μg/g) wet weight.
TR = trace.
ND = not detected.

[1] PCB levels estimated by examining peak between DDD and DDT with Aroclor 1254 as standard.
[2] Samples from each site composed of 10 birds except as indicated.
[3] Sample composed of 9 birds.
[4] Sample composed of 7 birds.
[5] Sample composed of 5 birds.
[6] Sample composed of 8 birds.

DIELDRIN

The difference between summer 1967 and winter 1967-68 dieldrin residue levels was much greater than that for DDT, and this seasonal difference was highly significant (Table 2). Residue levels the following fall were significantly lower than the summer/winter means. The vast majority of dieldrin residues found in the environment are derived from use of aldrin; aldrin/dieldrin sales (*5*) are roughly correlated with residue levels in starlings (Fig. 2). Results suggest that dieldrin levels may decline slightly in 1974 but should drop sharply in 1975 with the suspension of most uses of aldrin/dieldrin. Again, a more reliable fix on the slope will be generated from future collections.

Highest dieldrin residues (Table 4) were found in Washington (1-B-2), Idaho (1-B-1), Illinois (2-G-3), Iowa (2-G-4), Missouri (3-G-4), Indiana (2-H-3), Florida (4-H-1 and 4-I-3), Ohio (2-I-2), and North Carolina (3-J-1).

BHC

The compound BHC, including alpha, beta, and gamma isomers, was found in nearly all samples taken. Levels were extremely low; the highest was 0.036 ppm. BHC levels from the 1972 collection are not compared with those from past collections because HCB is being reported separately for the first time.

HCB

Although HCB has been used primarily outside the United States as a grain fungicide, it is possible that the compound has contaminated the environment in this Nation through industrial uses. In general, HCB levels were quite low, 0.1 ppm or less; almost half the samples had residues of 0.005 ppm or less. There were two sites which had high residue levels: 1-A-2 in Washington (3.330 ppm) and 1-B-1 in Idaho (2.340 ppm). Two other sites in Washington (1-B-2 and 1-B-3) had HCB levels exceeding 0.5 ppm.

HEPTACHLOR EPOXIDE

Nearly all samples collected in 1972 contained residues of heptachlor epoxide. Levels were relatively low, ranging from 0.005 to 0.210 ppm; only three sites had levels exceeding 0.1 ppm. Oxychlordane, which has been reported with heptachlor epoxide in the past, is being reported separately this year. Direct comparisons between previous heptachlor epoxide levels and the 1972 results are not made at this time.

OXYCHLORDANE

A breakdown byproduct of chlordane, oxychlordane, was found in nearly all samples at very low levels. The highest residue detected was 0.1 ppm.

PCB'S

Except for three sites, PCB's were found in all samples at levels below 1 ppm. Exceptions were sites 3-B-3 in Nevada, 1.87 ppm; 4-G-3 in Louisiana, 1.020 ppm; and 4-H-3 in Alabama, 19.9 ppm. The 1970 Alabama level was estimated to be 24.3 ppm; further monitoring is planned at this site to attempt to identify the source of contamination.

Acknowledgments

Collections were made by field personnel of the Bureau of Sport Fisheries and Wildlife. Regional Pesticides Specialists of the Divisions of Wildlife Services, Fishery Services, and Ecological Services were responsible for coordinating and reporting collections and assuring that samples were received in proper condition by the contract laboratory. These specialists are John W. Peterson, Boston, Mass.; Donald W. Hawthorne, Atlanta, Ga.; James B. Elder, Twin Cities, Minn.; Harry Kennedy, Albuquerque, N. Mex.; Robert H. Hillen, Denver, Colo.; and David J. Lenhart, Portland, Ore. Dr. Elder and William E. Martin, Ecological Services Division, Twin Cities, Minn., both provided valuable editorial assistance and I. C. T. Nisbet, Massachusetts Audubon Society, suggested the method for extrapolating seasonal estimates.

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Baseline Concentrations of Polychlorinated Biphenyls and DDT in Lake Michigan Fish, 1971[1]

Gilman D. Veith[2]

ABSTRACT

Responding to the recommendations of the Lake Michigan Interstate Pesticide Committee, the author aimed to establish baseline data on polychlorinated biphenyls (PCB's) and DDT in Lake Michigan fish in 1971. Because the past 2 years had witnessed unprecedented legislative action to protect food resources and other aquatic species near the top of the food chain from persistent hazardous chemicals, the author also attempted to gauge the impact of cooperative legislative action on the quality of large lakes.

Thirteen species of fish taken from 14 regions of Lake Michigan in the fall of 1971 were analyzed for PCB's and DDT analogs. Mean wet-weight concentrations of PCB's similar to Aroclor 1254 ranged from 2.7 ppm in rainbow smelt to 15 ppm in lake trout. Most trout and salmon longer than 12 inches contained PCB's at concentrations greater than the tolerance level of 5 ppm established by the Food and Drug Administration, U.S. Department of Health, Education, and Welfare. Mean concentrations of total DDT ranged from less than 1 ppm in suckers to approximately 16 ppm in large lake trout. The presence of the major chlorinated hydrocarbons was confirmed by gas-liquid chromatography/mass spectrometry; additional PCB confirmations were obtained through perchlorination. The most abundant PCB's were tetra-, penta-, hexa-, and heptachlorobiphenyls which are similar to commercially prepared Aroclor 1254; lesser chlorinated PCB's were present in fish from nearshore waters.

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Introduction

This paper identifies and quantifies the most abundant organochlorine compounds, particularly polychlorinated biphenyls (PCB's) and DDT, in Lake Michigan fish in 1971. By establishing data on PCB's and DDT in Lake Michigan fish as recommended by the Lake Michigan Interstate Pesticide Committee, the author of the present study aimed to develop a 1971 baseline to predict trends of these chemicals in the lake. Lake Michigan contains much higher concentrations of potentially hazardous and persistent organic chemicals than the other Great Lakes, in part because of their widespread usage in the watershed and their disproportionally brief flushing period and low biomass density. Previous studies have shown that fish from Lake Michigan approach the action levels for dieldrin set by the Food and Drug Administration (FDA), U.S. Department of Health, Education, and Welfare (*1*); a major percentage of Lake Michigan fish exceeded the 5 ppm action level for DDT in 1969 (*2*). Similarly, Veith (*3*) has shown that PCB concentrations similar to Aroclor 1254 were greater than 15 ppm or three times the FDA action level in large fish captured from Lake Michigan in 1969.

Despite the comparatively high levels of DDT, dieldrin, and PCB's in Lake Michigan, there is no unequivocal evidence that they are endangering aquatic life. Concentrations of these chemicals appear to be below 10 parts per trillion (ppt) in the pelagic water and less than 100 ppt in nearshore waters. However, considerable indirect evidence suggests that the buildup of organochlorine compounds may threaten biological resources of the lake. Other reports have reviewed the chronic toxicity of pesticides and PCB's (*4-7*).

States surrounding Lake Michigan have made a major effort to restock the lake with brown, lake, and rainbow trout and coho and chinook salmon. Between 1963 and 1970, over 600,000 rainbow trout were released by Wisconsin alone (*8,9*). However, Reinert (*2*) previously noted that DDT and dieldrin levels in eggs of these fish are similar to concentrations which inhibited reproduction in the studies of Burdick et al. (*10*) and Macek (*11*). Johansson et al. (*12*) have shown that 15 ppm PCB's (lipid basis) in salmon eggs produced mortality in 50 percent of the samples tested. Death can be expected in all eggs when the PCB lipid content reaches 25 ppm.

Although continued stocking of fish may maintain a food resource, many fish contain residue body burdens which make them unfit for consumption. The effect of these fish on mink production in the North Central States has been studied in detail: before DDT and dieldrin concentrations in these fish had been well documented, Hartsough (*13*) indicated that the fish were suspected to inhibit mink reproduction; Aulerich et al. (*14*) clearly demonstrated that the fish had been the cause of the minks' reproductive failure; and Aulerich and Ringer (*15*) reported that DDT and DDD did not have significant adverse effects on mink. Furthermore, dieldrin was lethal to mink at 2.5 ppm in the food when fed for extended periods, but did not appear to affect reproduction at twice this concentration during the gestation period. Aulerich et al. concluded that feeding coho salmon to mink did not cause reproduction problems, but that the disorder is associated with other species of fish and ". . . appears to be dependent upon the species of fish and its environment" (*16*). Finally, after the earlier reports that PCB's were present in Lake Michigan fish, Ringer et al. (*17*) demonstrated that 10 ppm Aroclor 1254 in coho salmon produced 71 percent mortality in mink and that a mixture of 10 ppm PCB's and 0.5 ppm dieldrin in coho feed produced 100 percent mortality. No kits were born alive when the diet contained 5 ppm or more Aroclor 1254 alone. This clearly indicates that biological resources of Lake Michigan may seriously endanger other species even though concentrations of toxicants are not severe enough to produce readily discernible effects within the aquatic communities.

Equally important is the coincidence of high chlorinated hydrocarbon levels in herring gull and other bird populatons coupled with reproductive failures and subsequent population decline (*18*). Anderson (*19*) found that the eggs of the Great Lakes herring gull contained the highest chlorinated hydrocarbon levels ever reported for that species. He also found that the degree of eggshell thinning in the Lake Michigan gull, whose population declined dramatically in the early 1960's, varied from 9 percent in 1953-56 to 18 percent in 1965. In comparison, eggs of gulls on Lake Huron and Lake Superior have exhibited shell thinning of 7 percent and 8 percent, respectively, and those from gulls on the East Coast have remained essentially unchanged. Double-crested cormorants from Wisconsin had eggshells 20 percent thinner than those of gulls, and their eggs had the highest DDE concentrations of any cormorant eggs sampled from interior North America. Golden eagles, which feed primarily on mammals, do not show eggshell thinning as dramatic as that of bald eagles, which feed on fish (*19*).

Lake Michigan is the only Great Lakes watershed where major persistent chemicals have been curtailed. Although use of chlorinated pesticides in agriculture was probably diminishing in the late 1960's, the Lake Michigan Enforcement Conference recommended regulatory actions on many uses in 1968. This recommendation led to restrictions on DDT including its sale in Illinois, Michigan, and Wisconsin. A more detailed summary is presented by Lueschow (*20*). Monsanto Company, the sole producer of PCB's in the United States, restricted PCB sales in 1970; by April 1971 they were sold only to close-system users.

To measure the impact of the unprecedented cooperative legislative action regarding these chemicals, and to establish baseline data, the Lake Michigan Interstate Pesticide Committee recommended that this study be funded.

Sampling Procedures

Fish were collected in September and October 1971 with gill nets and pond nets from the four regions of Lake Michigan outlined in Figure 1. Whole fish were stored frozen (−20° C) in aluminum foil or polyethylene bags for 60 days or less and homogenized while frozen by repeatedly passing them through a meat grinder. All metal surfaces were rinsed with acetone, polyethylene bags were examined for interferences, and the grinder bearing and seal were checked periodically to assure that the sample was not contaminated during storage or preparation.

Analytical Procedures

REAGENTS

Sodium sulfate (Fisher Scientific Co.) was washed with three volumes of 1:1 hexane-acetone and dried at 130° C. To prevent further contamination from cap liners or containers, the Na_2SO_4 was stored in large glass bottles with aluminum foil liners in the cap.

The florisil (Kensington Chemical, Fisher Scientific Co.) was extracted in an all-glass Soxhlet extractor for 24 hours with the azeotrope of hexane and acetone to remove traces of organic impurities. The solvent was evaporated from the florisil at 100° C, and the solid was heated at 650° C for 2.5 hours for activation. If not used immediately after heating, the florisil was heated to 105° C before use.

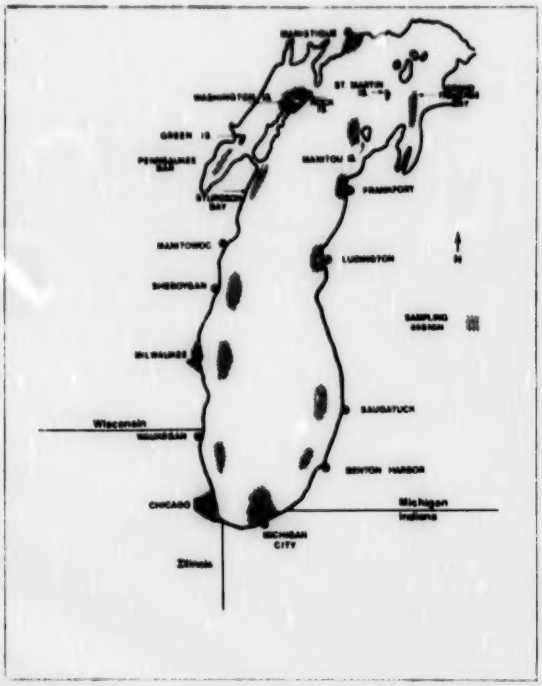

FIGURE 1. *Sampling regions for collecting fish, Lake Michigan—1971*

Other analytical components included:

Silicic acid:	Mallinckrodt Chemical, AR grade, Ramsey and Patterson. Used directly from reagent bottle.
Hexane:	Skelly B. Redistilled in glass from Dri-Sodium, Fisher Scientific Co.
Acetone:	Fisher Scientific Co., MCB. Redistilled in glass from Dri-Sodium, Fisher Scientific Co.
Ethyl ether and methylene chloride:	Mallinckrodt Chemical. Pesticide-quality solvents. Used directly from reagent bottle after periodic checks showed no interferences.
Glass wool:	Soaked in acetone, rinsed with 1:1 acetone:hexane mixture.
Glassware:	Washed thoroughly with hot detergent; rinsed once with hot water, twice with distilled water, again with 1:1 mixture of redistilled acetone:hexane.

PREPARATION OF SAMPLES

Procedures to extract and remove the bulk of the lipids have been described previously (*21*). Because of the high relative concentration of *p,p'*-DDE in Lake Michigan fish, DDE was quantitated directly by diluting 10 percent of the nonpolar florisil eluate to the appropriate volume for gas-liquid chromatographic (GLC) analysis. PCB's were separated from TDE and DDT isomers with a modified Armour and Burke procedure which omitted Celite 545 (*22*).

Quantitative gas chromatographic analyses were conducted on an Aerograph 17-5-20 gas chromatograph equipped with dual concentric-tube electron-capture detectors (^{3}H, 250 mc). Columns were 2.0-m-by-1.8-mm-ID glass coils packed with 3 percent OV-101 on 120/140-mesh Gas-Chrom Q. The carrier gas, purified N_2, was maintained at 20 ml/min; the injector, column, and detector temperatures were 240°, 180°, and 220° C, respectively. Chromatograms were recorded on a Varian model A-25 dual pen recorder.

Previous work (*21*) showed that fish from Lake Michigan contain mixtures of PCB's that closely resemble the Aroclor 1254 produced by Monsanto Company, although PCB's both heavier and lighter than those most abundant in Aroclor 1254 were also present. The fish extracts contain predominantly those PCB's which elute at 70, 84, a doublet of 98 and 104, 125, 146, and 176; peak height of *p,p'*-DDE is represented here as 100 (Fig. 2). The presence of DDE precluded the use of the 98 and 104 PCB components in the quantitation, and PCB's based on Aroclor 1254 were determined by summing the heights of the 70, 84, 125, 146, and 174 PCB components when peak height of DDE is 100. This method also decreased the effect of minor compositional variations on the analytical result.

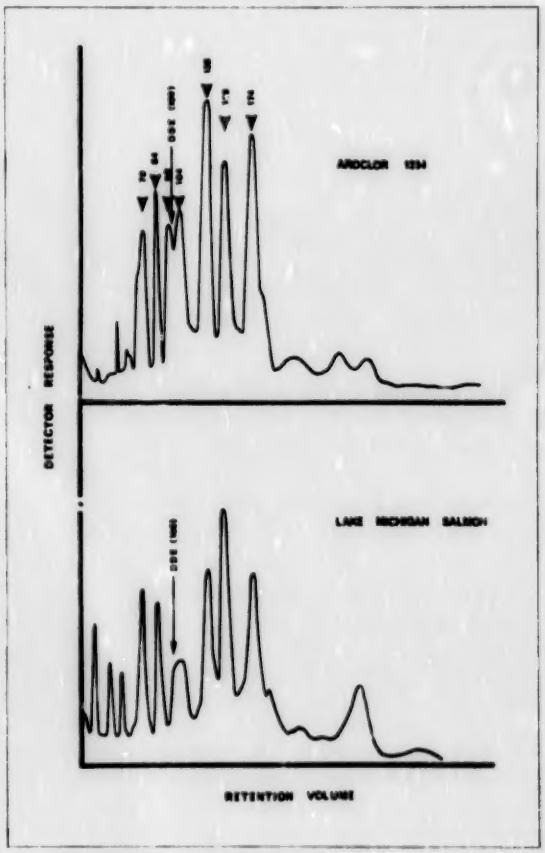

FIGURE 2. *Chromatograms of PCB mixtures in Aroclor 1254 and fish from Lake Michigan*

Recovery of PCB's from fish tissue averaged 85.1 ± 4.3 percent, whereas recovery of DDE was greater than 90 percent. The precision of the method outlined above is summarized in Table 1, which lists means and standard deviations of the analyses of six replicates of several fish species for PCB's, DDT, and lipids. The standard deviation for PCB analyses ranged from 5 percent in smaller fish to 14 percent in large coho salmon. The decrease in precision in analyses of large coho resulted from the difficulty of homogenizing larger fish. Precision was poorest in DDT analyses, where the standard deviation ranged from 8 to 23 percent with a mean of approximately 14 percent. This reduced precision results from losses during silicic acid chromatography which is used to quantitate the TDE and DDT isomers. The precision of DDE analyses was greater than those for DDT analyses, which was anticipated because of the fewer manipulations of the extracts. The standard deviation ranged from 7 to 18 percent, but the average deviation was approximately 10 percent. Because of the relatively simple procedure, lipid analyses were most precise, exhibiting standard deviations from 5 to 7 percent.

TABLE 1. *Precision of chlorinated hydrocarbon determinations for PCB's, DDE, DDT, and lipids in selected fish, Lake Michigan—1971*

Species	No. Replicates	Aroclor 1254	*p,p'*-DDE	*p,p'*-DDT	Lipid, %
Coho salmon (25 in.)	6	15.2±2.2	7.5±0.6	3.2±0.6	4.2±0.2
Coho salmon (27 in.)	6	13.1±1.3	5.5±0.4	1.8±0.4	10.0±0.6
Whitefish (13 in.)	6	4.1±0.2	0.35±0.04	0.56±0.04	16.2±0.9
Bloater (10 in.)	6	5.7±0.4	3.4±0.3	2.2±0.3	18.2±1.3
Alewife (8 in., composite)	6	4.0±0.2	1.1±0.2	1.0±0.2	5.7±0.3

NOTE: In columns 3-6, first number represents mean, second represents standard deviation.
Residues are ppm wet weight.

The determinable limit for PCB analysis was approximately 0.1 ppm; limits for *p,p'*-DDT, *o,p'*-DDT, *p,p'*-TDE, and *p,p'*-DDE were approximately 0.05 ppm.

CONFIRMATION OF MAJOR COMPONENTS

Major components of Lake Michigan fish extracts were characterized for a limited number of composite samples by standard gas-liquid chromatography/mass spectrometry techniques. In addition, the presence of PCB's in samples from each collection area was confirmed by perchlorination of PCB's to decachlorobiphenyl and subsequent analysis of the product by GLC (*23*). Aliquots of the hexane fraction of silicic acid columns were evaporated to dryness in a 5-ml vial fitted with a teflon-lined screw cap. Antimony pentachloride (0.2 ml) was added to the residue, and the vial was sealed and held at 180° C for 6 hours. Approximately 1 ml 6N MCl was added to the products to remove the $SbCl_5$ and the solution was extracted with five 1-ml hexane portions. The hexane was passed through a disposable pipette containing anhydrous Na_2SO_4 to remove traces of the aqueous solution. The sample was collected in a graduated centrifuge tube and diluted to the proper volume for GLC analysis. This technique also provided semiquantitative information for PCB's to supplement direct GLC analysis of the extracts. For those samples which contained PCB's similar to Aroclor 1254, estimates of total PCB's by perchlorination were within 15 percent of direct GLC analysis.

Results and Discussion

Approximately 850 fish were analyzed for PCB mixtures most closely resembling Aroclor 1254; a summary is presented in Table 2. Mean concentrations ranged from 2.7 ppm in smelt to 15.5 ppm in lake trout. Larger fish, such as brown, lake, and rainbow trout and chinook and coho salmon, contained PCB's at mean concentrations two to three times the 5 ppm action level established by FDA (*1*). Mean PCB concentrations in redhorse suckers, smelt, and whitefish were considerably less than 5 ppm. Mean concentrations in the alewife, carp, chub, and yellow perch were approximately 5 ppm; the range was 4.2-6.0 ppm. As expected, PCB levels increased with the percentage of fat and size of fish.

In Lake Michigan fish the mean concentration of total DDT, the sum of *p,p'*-DDT, *o,p'*-DDT, *p,p'*-TDE, and *p,p'*-DDE, ranged from 0.9 ppm in carp to 7.1 ppm in lake trout (Table 2). As with PCB's, fish with higher lipid concentrations contained greater concentrations of DDT.

The ratio of PCB's to total DDT ranged from 1.3 in redhorse suckers caught primarily in the northern waters to 7.6 in carp. The ratio of PCB's to DDT in the majority of the fish was between 1.7 and 2.8, and only in the carp, redhorse, yellow perch, and white sucker did the ratios fall outside this range. This ratio may become important in future studies to determine the rates at which the chemicals are eliminated from the Lake Michigan system.

Mean ratios of *o,p'*-DDT to *p,p'*-DDT ranged from 0.1 to 0.3; this ratio in the majority of the fish was 0.2. Since technical DDT generally contains about 30 percent of the *o,p'*-DDT isomer (ratio, 0.4), data from Lake Michigan fish suggest that degradation, other removal mechanisms, or both in the lake are slightly greater for the *o,p'* isomer than for the *p,p'* isomer. More than 80 percent of the total DDT residue is accounted for by *p,p'*-DDE and *p,p'*-DDT.

Not only did PCB concentrations vary considerably among the 13 species captured, but the range of PCB concentrations in a single lake species was generally

greater than 100 percent. The concentration range in red suckers was less, but all were captured in the same region of the lake. Although some variation in concentrations is expected because of the normal analytical error, the much larger ranges in Table 2 are undoubtedly due to other factors that limit usefulness of the mean concentrations presented. Previous research has shown that the lipid content, size of fish, season of capture, and concentration in the water may affect considerably the observed concentration of chlorinated hydrocarbons in tissue (2).

CHLOROBIPHENYLS

Regional variation in PCB concentrations and variations due to lipid content for each species are shown in Table 3. The wet-weight concentration of PCB's in ale-

TABLE 2. *Major chlorocarbons in fish, Lake Michigan– 1971*

Species [1]	No. Fish Analyzed	Mean Fish Weight, g	Mean Lipid, %	Mean PCB's	Mean DDE	Mean ΣDDT	Mean PCB/ ΣDDT	Mean DDE/ ΣDDT	Mean *o,p'*-DDT/ *p,p'*-DDT
Alewife	85	100	6.5[3.9]	4.6[2.1]	1.7[0.8]	2.2[1.1]	2.4	0.8	0.2
Bloater	287	249	20.0[5.9]	6.0[2.2]	2.5[1.1]	3.8[2.8]	2.2	0.7	0.2
Brown trout	17	3,650	15.5[4.1]	7.3[2.8]	2.7[1.0]	4.2[1.6]	1.8	0.6	0.1
Carp	42	2,160	10.0[7.0]	4.2[3.6]	0.7[0.9]	0.9[1.2]	7.6	0.8	0.3
Chinook salmon	21	3,100	5.0[3.9]	11.4[4.0]	5.2[1.5]	6.8[2.5]	1.7	0.8	0.2
Coho salmon	56	2,720	6.5[2.1]	11.5[5.7]	4.8[2.3]	6.3[2.8]	2.1	0.7	0.2
Lake trout	134	1,620	16.6[4.3]	15.5[3.3]	5.0[2.8]	7.1[3.7]	2.5	0.7	0.2
Yellow perch	44	148	6.1[1.7]	5.8[1.5]	1.0[0.6]	1.6[1.1]	4.8	0.8	0.1
Rainbow trout	11	4,190	18.4[3.3]	9.3[4.1]	3.4[1.3]	4.2[1.8]	2.3	0.8	0.2
Redhorse sucker	16	902	8.6[1.2]	3.0[0.7]	1.6[0.5]	2.6[0.7]	1.3	0.6	0.2
Smelt	38	51	5.8[1.8]	2.7[1.3]	0.8[0.4]	1.2[0.6]	2.6	0.7	0.1
White sucker	51	1,130	5.9[2.8]	3.9[3.6]	1.0[0.5]	1.6[1.2]	3.4	0.7	0.1
Whitefish	43	1,170	17.6[4.4]	3.0[1.9]	0.8[0.3]	1.4[0.6]	2.8	0.7	0.2

NOTE: Expressions in brackets represent standard deviations.
Residues are ppm wet weight.
[1] Scientific names appear in Table 3.

TABLE 3. *Mean concentrations of PCB's and DDT in fish, Lake Michigan—1971*

Location	Capture Date	No. Fish Analyzed	PCB's	Percentage Fish Above 5 ppm PCB's	PCB's, Lipid Weight	*p,p'*-DDE	*p,p'*-TDE	*p,p'*-DDT	*o,p'*-DDT	Total DDT	Percentage Fish Above 5 ppm DDT
Alewife (*Alosa pseudoharengus*)											
Michigan City	10/15	10	4.4[2.0]	40	164	1.4	0.19	0.5	0.08	2.2	10
Benton Harbor	9/2	10	4.8[1.1]	40	60	1.8	0.23	0.5	0.08	2.7	0
Waukegan	8/23	2	2.5[0.1]	0	47	1.0	0.18	0.5	0.07	1.6	0
Saugatuck	4/11	12	5.3[2.2]	41	51	1.8	0.22	0.8	0.10	2.7	11
Sheboygan	10/15	4	5.5[1.4]	50	79	2.2	0.20	0.7	0.07	3.2	0
Ludington	7/3	16	4.4[1.4]	18	207	ND	ND	ND	ND	ND	ND
Frankfort	10/5	10	3.7[1.2]	20	62	1.3	0.16	0.4	0.06	1.9	0
Manitou Island	9/10	3	3.8[2.2]	33	51	3.2	0.33	1.3	0.16	5.0	30
Rock Island	9/11	3	8.9[12.0]	66	182	1.1	0.11	0.3	0.04	1.5	0
St. Martin Island	9/11	6	3.5[1.3]	16	82	1.0	0.14	0.3	0.05	1.5	0
Brown trout (*Salmo trutta*)											
Michigan City	10/15	1	11.9[0.0]	100	51	3.7	0.70	1.7	0.22	8.4	100
Sheboygan	7/13	5	7.9[3.0]	100	42	2.6	0.46	1.2	0.18	4.4	25
Gills Rock	9/16	10	6.7[2.5]	70	54	2.8	0.48	1.0	0.14	4.4	40
Carp (*Cyprinus carpio*)											
Michigan City	11/29	2	11.0[0.2]	100	72	3.3	0.81	0.3	0.14	4.6	50
Saugatuck	10/15	15	4.6[4.8]	20	71	0.6	0.20	0.1	0.02	0.9	0
Sheboygan	7/23	11	1.7[0.8]	0	30	0.2	0.07	0.0	0.01	0.3	0
Pensaukee Bar	11/1	9	4.2[1.4]	33	30	0.8	0.19	0.0	0.01	1.0	0
Manitou Island	9/16	5	5.8[0.8]	80	30	ND	ND	ND	ND	ND	ND
Bloater (*Coregonus hoyi*)											
Benton Harbor	9/2	10	5.0[1.2]	60	24	2.5	0.31	1.5	0.19	4.5	30
Saugatuck	6/16	18	8.1[1.9]	88	46	1.9	0.47	1.8	0.19	4.3	37
Saugatuck	6/18	24	7.8[2.2]	95	43	2.4	0.63	2.4	0.25	5.7	64
Saugatuck	6/19	15	6.9[1.8]	86	34	1.8	0.47	2.5	0.31	5.1	66
Milwaukee	9/19	11	4.6[1.2]	36	28	3.4	0.36	2.0	0.26	6.0	88
Sheboygan	7/13	13	5.1[1.5]	61	31	1.3	0.40	2.2	0.24	4.1	50
Sheboygan	7/22	13	6.1[1.8]	76	21	3.4	0.34	2.0	0.24	5.9	81

(Continued next page)

TABLE 3 (cont'd.). *Mean concentrations of PCB's and DDT in fish, Lake Michigan—1971*

Location	Capture Date	No. Fish Analyzed	PCB's	Percentage Fish Above 5 ppm PCB's	PCB's, Lipid Weight	*p,p'*-DDE	*p,p'*-TDE	*p,p'*-DDT	*o,p'*-DDT	Total DDT	Percentage Fish Above 5 ppm DDT
Sheboygan	8/19	6	3.8[0.6]	0	15	2.6	0.35	1.3	0.16	4.4	20
Sheboygan	8/27	7	5.0[1.3]	57	23	3.2	0.47	2.3	0.28	6.2	80
Sheboygan	10/15	6	3.7[0.8]	0	21	2.4	0.28	1.7	0.17	4.5	42
Ludington	7/3	43	7.4[1.8]	93	41	2.0	0.58	2.2	0.28	5.0	46
Frankfort	10/5	8	4.7[0.7]	12	28	2.2	0.33	1.2	0.16	3.8	0
Manitou Island	9/10	10	4.6[1.1]	30	24	3.1	0.50	1.8	0.26	5.6	50
Washington Island	9/9	6	4.1[0.6]	0	16	3.2	0.34	1.9	0.18	5.6	60
Rock Island	9/11	6	5.8[2.5]	66	97	2.8	0.36	1.1	0.08	4.4	20
Rock Island	9/14	7	5.6[1.6]	57	23	2.7	0.42	2.0	0.22	5.4	50
Rock Island	9/16	8	4.0[0.7]	12	18	2.8	0.29	1.3	0.14	4.5	40
St. Martin Island	7/19	9	3.4[0.6]	0	16	2.2	0.34	1.1	0.17	3.8	0
Manistique	5/27	9	4.8[0.7]	33	26	2.9	0.42	1.8	0.14	5.2	80
Chinook salmon (*Oncorhynchus tschawytscha*)											
Milwaukee	10/15	1	24.0[0.0]	100	117	6.6	1.67	4.7	0.53	13.6	100
Manitowoc	10/21	8	11.3[3.1]	100	209	6.3	0.62	1.2	0.21	8.3	100
Strawberry Creek	10/21	10	9.9[2.8]	100	373	4.5	0.39	1.0	0.17	8.0	88
Gills Rock	9/16	2	12.7[0.7]	100	278	5.5	0.44	1.2	0.20	7.3	100
Coho salmon (*Oncorhynchus kisutch*)											
Michigan City	4/17	8	3.6[1.7]	12	51	0.8	0.17	0.6	0.08	1.6	0
Michigan City	9/27	8	17.3[8.4]	87	255	5.3	0.46	1.2	0.20	7.2	85
Michigan City	10/7	6	14.0[4.0]	100	349	4.5	0.41	1.4	0.18	6.5	60
Sheboygan	10/21	9	12.1[2.8]	100	276	6.6	0.57	1.4	0.27	8.8	100
Ludington	8/28	4	11.2[3.3]	100	108	6.8	0.39	0.9	0.19	8.3	100
Platte River	10/7	10	12.9[1.3]	100	226	5.5	0.48	1.4	0.24	7.6	100
Gills Rock	9/16	11	12.6[4.1]	90	166	4.9	0.45	1.2	0.20	6.7	87
Lake trout (*Salvelinus namaycush*)											
Michigan City	10/15	4	14.9[2.0]	100	89	2.9	0.88	3.1	0.35	7.3	100
Michigan City	9/8	3	21.2[6.8]	100	121	9.5	1.12	3.9	0.45	14.9	100
Saugatuck	6/21	14	11.9[3.8]	100	70	4.7	0.65	2.1	0.27	7.6	88
Saugatuck	7/10	7	15.5[2.4]	100	78	6.9	0.70	2.0	0.24	9.8	100
Saugatuck	10/1	9	18.7[4.7]	100	113	6.7	0.84	2.8	0.27	10.6	100
Milwaukee	9/14	1	21.2[0.0]	100	90	10.1	0.96	3.0	0.47	14.5	100
Milwaukee	9/19	7	21.1[6.0]	100	114	10.6	1.05	3.3	0.45	15.4	100
Milwaukee	10/15	12	10.4[3.6]	100	127	2.3	0.44	1.3	0.15	4.2	20
Sheboygan	7/1	1	14.9[0.0]	100	58	ND	ND	ND	ND	ND	ND
Sheboygan	7/13	36	12.5[3.2]	100	82	4.3	0.51	1.7	0.24	6.8	64
Ludington	7/1	10	8.1[1.8]	100	51	3.3	0.52	1.6	0.22	5.6	60
Ludington	7/4	8	8.5[1.7]	100	58	3.2	0.63	2.0	0.30	6.1	66
Grand Traverse Bay	10/19	8	11.3[5.3]	75	56	6.0	0.73	2.0	0.30	9.0	77
Green Island	7/21	19	9.0[1.7]	100	48	3.8	0.50	1.5	0.21	6.0	72
Gills Rock	9/16	10	14.7[6.4]	100	83	5.5	0.62	1.9	0.24	8.3	62
Yellow perch (*Perca flavescens*)											
Michigan City	10/15	14	4.2[0.7]	14	72	0.8	0.15	0.4	0.04	1.3	0
Waukegan	8/28	9	6.1[1.5]	88	78	ND	ND	ND	ND	ND	ND
Milwaukee	10/13	10	10.9[3.1]	90	203	1.1	0.30	0.7	0.08	2.1	0
Ludington	7/6	3	6.2[1.3]	100	139	2.2	0.30	0.9	0.13	3.6	0
Frankfort	10/12	2	5.4[1.8]	50	69	1.7	0.43	2.2	0.14	4.5	0
Pensaukee Bar	8/25	10	2.7[2.1]	10	49	0.4	0.10	0.0	0.01	0.5	0
Rainbow trout (*Salmo gairdneri*)											
Michigan City	10/15	1	12.0[0.0]	100	66	ND	ND	ND	ND	ND	ND
Gills Rock	9/16	9	8.8[4.3]	77	47	3.1	0.34	0.9	0.16	4.5	40
Redhorse (*Moxostoma* sp.)											
Rock Island	9/11	7	2.8[0.9]	0	33	1.7	0.30	0.6	0.09	2.7	0
St. Martin Island	9/11	9	3.2[0.5]	0	37	1.5	0.35	0.8	0.09	2.7	0
Rainbow smelt (*Osmerus eperlanus mordax*)											
Michigan City	10/15	15	3.2[0.9]	0	45	0.9	0.11	0.4	0.04	1.4	0
Sheboygan	10/15	3	0.7[0.2]	0	18	0.6	0.12	0.3	0.03	1.0	0
Green Island	7/21	5	2.6[1.1]	0	57	0.7	0.12	0.2	0.02	1.0	0
Rock Island	9/11	8	2.9[1.7]	25	49	1.0	0.14	0.5	0.05	1.6	0
St. Martin Island	7/19	4	1.3[0.3]	0	31	0.7	0.09	0.2	0.04	1.0	0
White sucker (*Catostomus commersoni*)											
Michigan City	10/15	6	10.6[4.0]	100	100	1.8	0.32	1.8	0.08	4.6	66
Saugatuck	10/15	3	6.0[2.9]	66	149	0.7	0.14	0.2	0.03	1.0	0
Saugatuck	10/18	5	2.3[0.4]	0	40	ND	ND	ND	ND	ND	ND
Pensaukee Bar	8/6	7	3.2[3.1]	14	57	0.3	0.15	0.2	0.04	0.7	0
Grand Traverse Bay	10/19	14	2.3[0.7]	0	68	0.4	0.31	0.4	0.03	2.1	0
Green Island	7/21	1	2.1[0.0]	0	20	0.7	0.19	0.4	0.08	1.3	0
Rock Island	9/11	14	2.5[0.9]	0	46	0.9	0.20	0.3	0.04	1.4	0

(Continued next page)

TABLE 3 (cont'd.). *Mean concentrations of PCB's and DDT in fish, Lake Michigan—1971*

Location	Capture Date	No. Fish Analyzed	PCB's	Percentage Fish Above 5 ppm PCB's	PCB's, Lipid Weight	*p,p'*-DDE	*p,p'*-TDE	*p,p'*-DDT	*o,p'*-DDT	Total DDT	Percentage Fish Above 5 ppm DDT
Lake whitefish (*Coregonus clupeaformis*)											
Michigan City	10/15	4	6.1[0.9]	100	25	0.5	0.32	0.5	0.06	1.4	0
Saugatuck	6/19	7	2.7[0.5]	0	15	0.6	0.21	0.4	0.08	1.3	0
Saugatuck	6/21	2	3.1[1.3]	0	18	ND	ND	ND	ND	ND	ND
Grand Haven	9/6	7	5.8[0.9]	71	25	0.7	0.38	0.8	0.10	1.9	0
Grand Traverse Bay	10/19	13	1.8[0.3]	0	13	1.2	0.25	0.4	0.08	2.0	0
Rock Island	9/11	10	1.5[0.2]	0	9	0.7	0.16	0.4	0.05	1.4	0

NOTE: Expressions in brackets represent standard deviations.
ND = not determined.
Residues are ppm wet weight.

wives was greater in southern Lake Michigan than in the northern regions, although anomalies are apparent. Most alewives captured south of a line between Saugatuck and Sheboygan contained between 4.4 and 5.5 ppm PCB's, whereas those caught north of the line contained between 3.5 and 4.4 ppm. An interesting exception occurred in alewives from Rock Island just off the Door County Peninsula in Wisconsin; mean PCB concentration was 8.9 ppm.

Analysis of brown trout suggested similar trends: those from Michigan City at the southern end of the lake contained 11.9 ppm PCB's, whereas those from Sheboygan and Gills Rock contained 7.9 and 6.7 ppm PCB's, respectively.

Carp from Michigan City also had higher levels of PCB's than had those from the northern region. In contrast to the 11.0 ppm found in the Michigan City carp, those from Saugatuck and Sheboygan contained 4.6 and 1.7 ppm, respectively.

PCB's in bloaters in southern Lake Michigan ranged from 4.6 ppm near Milwaukee to 8.1 ppm near Saugatuck. In general, bloaters from the northern regions had concentrations below 5 ppm. The concentration of PCB's in the five groups of bloaters collected near Sheboygan during a 3-month period varied from 3.7 to 6.1 ppm, although the mean was below 5 ppm; no trend was indicated. The variation is somewhat less when data are expressed on a lipid basis; for example, PCB concentrations in the August 27 and October 15 bloaters were 5.0 and 3.7 ppm wet weight, respectively. In contrast, the concentration of PCB's in lipids was 23 ppm and 21 ppm, respectively. Thus much of the observed variation is caused by the variation in lipid content of fish.

All chinook salmon captured in Wisconsin contained more than 5 ppm PCB's; mean concentrations ranged from 9.9 ppm in Strawberry Creek (Sturgeon Bay) to 24 ppm at Milwaukee.

In concentrations of PCB's among coho salmon, authors observed little evidence of a trend dependent upon sampling region. Except for coho caught early in 1971 near Michigan City, mean concentrations of PCB's ranged from 11.2 ppm in salmon near Ludington to 17.3 ppm in those near Michigan City.

Among lake trout PCB concentrations were greatest in those from Michigan City, Saugatuck, and Milwaukee, where mean concentrations were generally between 15 and 21 ppm. Trout from the northern areas such as Sheboygan, Ludington, Grand Traverse Bay, and Gills Rock contained considerably less, and mean concentrations ranged between 8 and 15 ppm.

Mean concentration of PCB's was unexpectedly high, 10.9 ppm, in the 10 yellow perch caught near Milwaukee. Perch from other regions averaged less by a factor of two, and those from lower Green Bay contained 2.7 ppm.

In seven Rock Island redhorse, PCB residues averaged 2.8 ppm. In nine specimens from St. Martin Island, mean concentration was 3.2 ppm.

Rainbow trout were caught only near Michigan City and Gills Rock. The Michigan City rainbow trout had 12.0 ppm PCB's, whereas those from Gills Rock averaged only 8.8 ppm.

Concentrations of PCB's in white suckers and smelt were generally between 2 and 4 ppm, although the average concentration was 6.0 ppm in the three white suckers from Saugatuck on October 15 and 10.6 ppm in the six from Michigan City the same day. Except for whitefish caught at Grand Haven and Michigan City, the PCB concentration in whitefish was less than 3.1 ppm.

DDT AND ANALOGS

Concentrations of *p,p'*-DDT, *o,p'*-DDT, *p,p'*-TDE, and *p,p'*-DDE are presented in Table 3 along with the total DDT and percentage of fish that contained residues above the 5ppm action level established by FDA (*1*). Total DDT in alewives ranged from 1.6 ppm near Waukegan to 5.0 ppm near the Manitou Islands. There was no trend in the variations according to region. A brown trout from Michigan City contained 8.4 ppm total DDT, whereas those from Sheboygan and Gills Rock averaged 4.4 ppm. Except for the carp from Michigan City, which averaged 4.6 ppm total DDT, average concentrations in Lake Michigan carp were 1.0 ppm or less.

Total DDT in bloaters ranged from 3.8 ppm at Frankfort and St. Martin Island to 6.2 ppm at Sheboygan. There are no trends for DDT in chubs (Table 3). Except for eight coho salmon caught near Michigan City in the spring, which averaged 1.6 ppm total DDT, total DDT in this species varied little throughout the lake. Mean concentrations ranged between 6.5 and 8.8 ppm.

Lake trout from Michigan City averaged 14.9 ppm total DDT on September 8, 1971; those caught October 15, 1971, averaged only 7.3 ppm. The discrepancy is likely due to size differences. For example, the lake trout caught near Milwaukee in September also contained a mean concentration of approximately 15 ppm; however, the smaller trout caught near Milwaukee in October averaged only 4.2 ppm total DDT. DDT concentrations in lake trout from northern areas of the lake were less than 8 ppm; approximately 60-70 percent of the lake trout contained over 5 ppm total DDT.

Yellow perch from Pensaukee Bar in lower Green Bay had the lowest DDT content, 0.5 ppm; perch from other areas contained between 1.3 and 4.5 ppm total DDT. None of the perch contained more than 5 ppm total DDT.

Concentration of DDT in smelt, whitefish, and white suckers averaged approximately 1-2 ppm, although white suckers from Michigan City averaged 4.6 ppm total DDT.

Summary

Concentration of PCB's ranged from less than 2 ppm in small fish with low lipid content to over 20 ppm in larger fish with higher lipid content. The concentration of PCB's in Lake Michigan coho salmon is two to three times greater than in coho from Lake Huron, approximately 1.5 times greater than in Lake Ontario coho salmon, and approximately 10 times greater than in coho from Lakes Erie and Superior. Essentially 100 percent of large salmon and trout, both popular food sources, and 50-80 percent of bloaters from Lake Michigan contain PCB concentrations greater than the 5 ppm tolerance level set by FDA. Additional monitoring of this watershed is needed to determine whether tissue concentrations will reflect restrictions in domestic PCB sales and possible decreases in PCB usage in the watershed even though U.S. production of Aroclor 1254 has remained essentially the same as in 1969 (*24*).

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